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LABORATORY AND THEORETICAL STUDIES OF BAROCLINIC PROCESSES

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Collaborators:

Experiments:
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Numerical modeling:
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Theoretical/analytical:
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OBJECTIVES:

This research is aimed at developing an understanding of fundamental processes which may be important in the atmosphere, and at supporting the definition and analysis of baroclinic experiments utilizing the GFFC apparatus in micro-gravity space flights. Included are studies using numerical codes, theoretical models, and terrestrial laboratory experiments. The numerical modeling is performed in three stages: calculation of steady axisymmetric flow, calculation of fastest-growing linear eigenmodes, and nonlinear effects (first, wave-mean flow interactions, then wave-wave interactions). The code can accommodate cylindrical, spherical, or channel geometry. It uses finite differences in the vertical and meridional directions, and is spectral in the azimuthal. The theoretical work has been mostly in the area of effects of topography upon the baroclinic instability problem. The laboratory experiments are performed in a cylindrical annulus which has a temperature gradient imposed upon the lower surface and an approximately isothermal outer wall, with the upper and inner surfaces being nominally thermally insulating.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Although the PI has been at NASA Headquarters for the year, work has proceeded in all areas. Dr. Fehribach has utilized the axisymmetric/linear wave code to analyze flows which would occur in a GFFC apparatus which had "Earth-like" meridional temperature gradients, i.e., heated equator and cooled pole, with vertical stability imposed by having the outer sphere warmer than the inner. A transition curve was computed in thermal Rossby number (Ro), Taylor number (Ta) space. (The transition curve separates the region in which the axisymmetric flow is stable from that which is unstable.) Similar to the experiments that would actually be performed in space, Ro was varied by fixing the boundary temperatures and varying the artificial radial gravity. The transition curve for relatively low rotation rate (Ta) was very similar to that computed for the heated

pole (which is how the current hardware must be operated) by the PI the previous year, but for faster rotation there is a big difference. Centrifugally induced buoyant instabilities occur for small enough Ro, which give rise to another transition curve which intersects the baroclinic instability curve. This causes the axisymmetric flow to be unstable regardless of Ro (for large enough Ta). Thus, there appears to be an advantage to heating the pole and cooling the equator, at least in terms of performing analysis near the transition curve.

Ms. Payne and Dr. Chou have worked on further development of the numerical code. Ms. Payne implemented wave-mean flow feedback, so that the amplitude of a single unstable wave could be determined. The results were carefully checked against the only available published results, those of Williams and Quon. The present code disagrees with Williams and Quon for the single case they analyzed in the sense that wavenumber 5 (which is the only one they considered) equilibrates at a lower amplitude than theirs. Our wave number 4 case looks very much like their wave number 5. We have obtained some output and diagnostics from Quon's code supplied to us by Dr. Richard Pfeffer, FSU, with which we can compare our code. Most of the numerical techniques used by the codes are identical, and the numerical values of the terms should be the same. We suspect that the difference is in the advection of meridional and vertical momentum, where there are differences in the formulation. Detailed comparison and determination of the cause for the difference may be completed by the time we have our review meeting. Dr. Chou has begun work to include multiple azimuthal waves with wave-wave interactions. This will allow fully nonlinear simulations of fluid flow in a broad range of applications.

Theoretical studies by Drs. Chou and Reynolds consider the effects of topography on baroclinic instability. Dr. Reynolds was partially supported by this task, but he is proposing to expand his work separately, and the description of his work is not included here. Dr. Chou has developed a spectral numerical model for a rotating infinite channel to study the effect of topography on nonlinear baroclinic disturbances. Both its effect on exciting a disturbance of the same scale and its ability to modulate disturbances of another scale are examined. He finds that topography generates a short period modulation which superimposes on a long time nonlinear baroclinic evolution pattern that could be produced in the absence of topography. The topography has a tendency to phase-lock the disturbance, especially the topographic mode, while the baroclinicity leads to the propagation of the disturbance, especially the most unstable mode.

Further work on the cylindrical annulus laboratory experiments has been hampered by leakage problems with the turntable supplied by Contraves-Goerz. Currently, the table is back at the factory for repair. In the past year, Drs. Reynolds and Leslie completed calibration of the thermistors in the cylindrical apparatus (so that boundary temperatures can be determined), and wrote software for an Apple IIe computer so that the boundary temperature profile can be easily computed from resistance data. Preliminary experiments performed before the turntable malfunctioned showed interesting development of the spin-up process, which begins with small-scale convection arranged in rings around the annulus, and ends with smooth,

baroclinic waves. Transition to longer wavenumbers after the baroclinic waves form was observed, which occurs due to the combining of two waves and the spreading out of the others. It is hoped that these experiments will point to interesting cases which can be done in spherical geometry using the GFFC apparatus, and that they can be simulated in detail by the numerical code.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

As stated above, the new developments in the numerical code are being checked against other codes and sources for discrepancy are being sought. Depending upon the results of that analysis, changes in the code may or may not be made. After that process, the code will be used to more precisely define baroclinic experiments with GFFC on the IML-1 mission. The code will also serve as a valuable general research tool for studying dynamical processes in spherical and cylindrical geometry, hopefully better tying together much of the past laboratory work with the cylindrical annulus with the spherical atmosphere. The code will be used to analyze the results of the terrestrial laboratory studies, as well as being further verified by comparison with the laboratory results.

To investigate the topographically induced short-period modulation, a low truncation version of the spectral model will be employed to identify its source and physical mechanisms. The nonlinear interaction between a resonant topographic wave and a weakly unstable baroclinic wave, similar to that studied by Nathan, will also be examined. Preliminary results show a very good agreement between our numerical results and Nathan's analytical results. In the future, we will relax Nathan's parametric restrictions (e.g., weak supercriticality and small topographic height) to examine the validity of the analytical solutions and to extend the results in a broader parameter space.

When the turntable is returned from the factory, we will perform the experiments to determine a regime diagram for one set of external parameters (vertical depth, Prandtl number). This diagram will include the wave/axisymmetric transition curve as well as observed equilibrated wavenumber. The spin-up process will be documented and can be compared with the results of numerical simulations.

PUBLICATIONS:

T. L. Miller, "Baroclinic instability in a spherical space laboratory experiment," in process of revision (further work, including possible expansion of scope and adding authors, is pending PI's return to MSFC).

T. L. Miller, "On the design of baroclinic space laboratory experiments in spherical geometry," Sixth Conference on Atmospheric and Oceanic Waves and Stability, Seattle, August, 1987.

J. Fehribach and T. L. Miller, "Numerical stability analysis for a geophysical fluid flow cell" Southeastern Geophysical Fluid Dynamics Conference, April, 1988.

S.-H. Chou and A. L. Loesch, "Effect of topography on supercritical baroclinic disturbances" to present in Palmen Memorial Symposium on Extratropical Cyclones, Helsinki, Finland, August, 1988.